ECONTECHMOD. AN INTERNATIONAL QUARTERLY JOURNAL – 2016, Vol.5, No.4, 69-72

CONCEPT OF USING HEURISTIC METHODS IN THE OPTIMIZATION OF ELECTRIC POWER SYSTEMS

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Received November 21.2016: accepted December 20.2016

Abstract. The dynamic development of information technologies has significantly improved the process of planning and controlling the operation of electrical power systems, nevertheless, we are still looking for methods and solutions which will allow to optimize EPS. The article describes heuristic methods which can be used in electrical power engineering and which will be used to solve OPF (Optimal Power Flow) problems.

Key words: electrical power system, optimization, heuristics.

INTRODUCTION

The attempts to optimize power systems both at the stage of planning the development and controlling their operation focused mainly on looking for a proper distribution of the generated power into the generating units minimizing the total cost of its generation [14]. This task was associated with the minimization of the objective function, which was the sum of the generation costs, and was referred to as the Economic Load Dispatch (ELD). In order to solve the ELD problem, it was necessary to know the characteristics of the particular source costs, which usually take a non-linear form, whereas the equality constraint resulted from the power balance in the system. In order to compute the non-linear objective function minimum with the equality constraint, the Lagrange function with the λ multiplier is used, where the values of the source capacity ensuring the objective function minimum are computed by equaling partial derivatives of the Lagrange function to zero [11, 15]. The computational problem arises when inequality constraints are taken into account, as well as the technical minima, maximum values of sources capacity, and also after consideration of the balance equality constraints caused by transmission losses of the whole network where the power sources and loads are connected:

$$P_{Gi\,min} \leq P_{Gi} \leq P_{Gi\,max} \tag{1}$$

Taking into consideration the above constraints, the problem in question can be solved in a similar way, but in order to fully optimize the electric power system operation, it is necessary to take into account the full conditions of an industrial grid operation and the constraints associated with it [7].

Introducing the designation of three vectors – the state vector – including the modules of source voltages U and their arguments δ

$$\boldsymbol{x} = \begin{bmatrix} \boldsymbol{U} \\ \boldsymbol{\delta} \end{bmatrix} \tag{2}$$

which meets the grid equation taking into account the enforcement vector w (power output collected in nodes)

$$\boldsymbol{w} = \begin{bmatrix} \boldsymbol{P}_{\mathrm{L}} \\ \boldsymbol{Q}_{\mathrm{L}} \end{bmatrix} \tag{3}$$

and steering vector s (power generated in nodes)

$$\boldsymbol{s} = \begin{bmatrix} \boldsymbol{P}_{\mathrm{G}} \\ \boldsymbol{Q}_{\mathrm{G}} \end{bmatrix} \tag{4}$$

the optimizing problem can be presented in a general form

$$F_c(x, w, s) \longrightarrow min \tag{5}$$

with equality constraints

$$g\,(x\,,w,\,s) = 0 \qquad 6)$$

and inequality constraints

$$h\,(x,\,w,\,s) \geq 0 \tag{7}$$

In order to calculate the minimum EPS balancing costs, the objective function of an OPF problem should be drawn as follows:

$$F_c(s) = \sum_{j=1}^{N_z} c \cdot P_{Gj} \tag{8}$$

where: P_{Gj} is active power generated by the source connected to the node j.

The objective function presented above includes the summation of the steering vector elements corresponding to the relevant grid nodes, and their number is defined as N_z. The elements of the steering vector are capacities of all sources operating in it. The detailed nature of equality and inequality constraints results from the formulas of a typical load-flow problem [7, 8] i.e.:

– inequality constraint resulting from the system technical minimum,

– inequality constraint resulting from the permissible limb capacities,

– inequality constraint resulting from the permissible foreign exchange balance,

– inequality constraint resulting from the permissible values of nodal voltages in the grid,

– inequality constraint resulting from the balance of the active and passive power generated and taken,

– constraint resulting from the consideration of the *N-1* criterion [7, 9].

HEURISTIC AND EVOLUTIONARY METHODS IN ELECTRIC POWER ENGINEERING

Due to computational difficulties in solving the OPF and SCOPF problems with traditional methods, alternative methods of optimization: heuristic methods and genetic algorithms are used more and more often. In contrast to the traditional methods, heuristic methods do not require the knowledge of the derivative of the objective function, they are not affected by the lack of continuity of a function or "getting stuck" of the computational process in a local minimum [7]. At the same time, evolutionary algorithms are more and more often used to solve difficult problems in various fields of technical sciences and turn out to be most useful in case of a great number of solutions in the Pareto sense [10, 13].

The task of the evolutionary algorithm is to analyze alternative solutions in order to choose the best or potentially best ones. Searching is done using the mechanisms of evolution and natural selection, which is associated with remembering for some time the selected parts of the history of this process [16, 17]. The principle of the evolutionary algorithm consists in the processing of a population of individuals, each of which is a proposal of a solution to a specific problem**.** All individuals are assigned a value, referred to as the fitness of an individual, moreover, they are equipped with a genotype, on the grounds of which a phenotype is created. Thus, the principle of the algorithm consists in making multiple loops where reproduction (genetic operations) is followed by assessment and succession [4]. Both the heuristic methods and evolutionary algorithms are universal methods which can be used for computations with any objective function, for example, analyzing a power flow problem which is connected with a time-consuming iterative process determining elements of a state vector. In spite of the fact that an objective function has the form of summation and as such it is easy to optimize, one of the computation groups – limb constraints, permissible current capacity of a line and transformers power rating – can be checked only on the grounds of a state vector which is hard to determine. In some sense, during computation these constraints are not visible and when they are included in the objective function it is difficult to determine which shape is assumed by the new objective function which is created in this way and which is subject to minimization [8]. A few heuristic methods which can be used to solve optimization problems in electrical power engineering are listed and described below.

THE VEGA ALGORITHM (SCHAFFER'S VECTOR EVALUATED GENETIC ALGORITHM)

The author of this method is Schaffer and it is used to solve multi-criteria problems. In case of this algorithm, the population of permissible individuals is divided into numerous subsets, the number of which is determined by the number of the accepted criteria. In each of these subsets, the best individuals are selected, but from the point of view of only one criterion in each subset of another one. (Fig. 1). Thus, it can be said that a multi-criteria problem has been decomposed into a number of autonomous single-criterion problems, which, however, are not explicitly related to one another. The selected best individuals are moved to a temporary population P', where they are mutated and modified through the use of crossover and mutation operations.

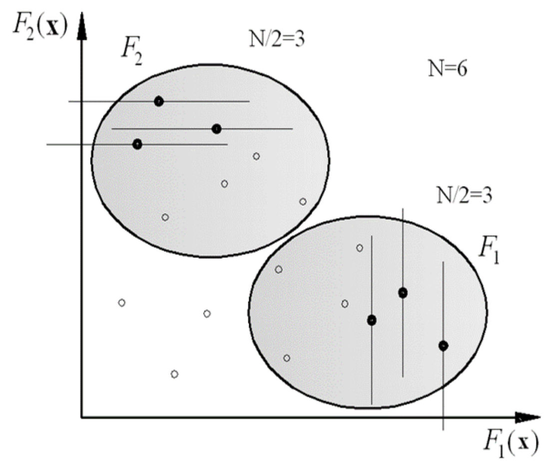

Fig. 1. Selection in the VEGA method for double-criteria maximization [12]

The steps of VEGA algorithm:

1. The PG population is divided into *k*-subsets where k stands for the number of criteria.

2. Selection of the best individuals in each *k* subsets, taking into consideration only one of *N/k* criteria, (where *N* – is the number of all selected individuals).

3. The resulting individuals are moved to a temporary population *P'*.

4. The crossover and mutation operation takes place in the population *P'*. A new population – *PG* is obtained, where *G=G+1*.

5. The procedures described in points 1 – 4 are repeated until the algorithm is terminated (e.g. *G* = 400).

THE HLGA ALGORITHM (HAJELA AND LIN'S WEIGHTING-BASED GENETIC ALGORITHM)

The algorithm was developed by Hajela and Lin and is based on the method of weighted criteria. The weights are coded together with individuals, thanks to which each individual evolves with differently defined criteria, which at the same time makes it possible to ensure many directions of the optimization task [5].

The steps of the HLGA algorithm:

1. Selection of an individual out of the present population *PG*.
2. Determination of weights of criteria validity and fitness.
3. Selection of the best-fitted individuals and adding them to the temporary population *P'*.
4. Generating new individuals - both as a result of crossover operations and of mutation.
5. Determination of the new population *PG*, where *G=G+1*.
6. The procedures described in points 1–5 are repeated until the algorithm is terminated (e.g. $G < 400$).

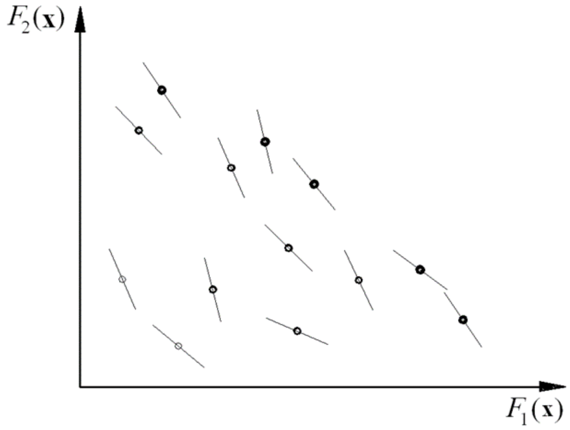

Fig. 2. HLGA method– assigning weights of criteria validity to the individuals [12]

FFGA ALGORITHM (FONSECA AND FLEMING'S MULTIOBJECTIVE GENETIC ALGORITHM)

The algorithm was developed by Fonseca and Fleming, its concept is very similar to the NSGA algorithm, because it also assigns ranks to non-dominated individuals from the set/subset of non-dominated solutions. The major difference, however, is that in the subsequent steps of the selection, the value of fitness depends not only on the number of the step, the value of the latest assigned rank, but also on the number of solutions which dominate them by the solutions forming an earlier front of the non-dominated solutions. There are numerous articles which present several ways of assigning ranks to particular individuals.

The paper [2, 4] uses a formula where the rank of the individual in question corresponds to the number of individuals dominating this individual, plus one. Such a procedure results in a diversity of ranks of the individuals belonging to the subsequent fronts. The individuals dominated by two individuals of the front 1 are assigned rank 3. When we use such a procedure where only individuals belonging to the previous front are taken into consideration, the diversity of ranks of the subsequent individuals will be smaller than in case of the formula described above.

In this situation the individuals of the subsequent front must have worse ranks than the individuals of the previous front, so they are assigned values of at least 4, but the individuals dominated by two individuals of front 2 are assigned a rank of 5. Transferring this procedure to the individuals forming the subsequent front, the first of them is assigned rank 6 and the other one – rank 7.

Steps of the FFGA algorithm:

1. We determine the ranks of all individuals in the population of permissible solutions P_G, remembering to temporary eliminate from the set of permissible solutions the individuals that have already been assigned ranks.
2. We sort the population according to the ranks assigned (ranging from the best to the worst one) and we assign values of initial fitness (according to the formula: *1/rank* value, e.g. ¼, $^{1}/_{7}$) to particular individuals.
3. We select the best-fitted individuals and add them to the temporary population *P'*.
4. We generate new individuals by crossover and mutation operations.
5. We determine a new population P_{G+1}.
6. The procedures described in points 1–5 are repeated until the algorithm is terminated (e.g.. $G < 400$).

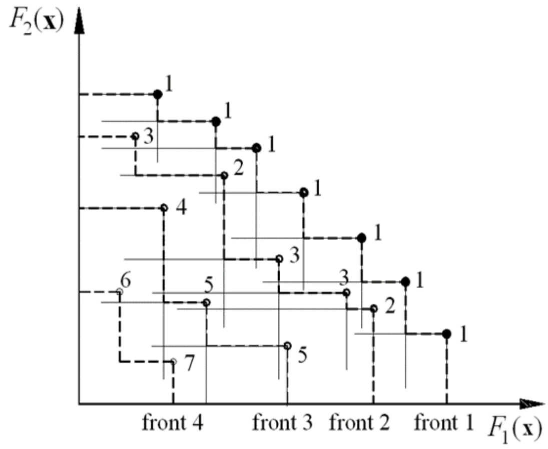

Fig. 3. Assigning ranks in a double-criteria maximizing problem – the FFGA algorithm [12]

THE NPGA ALGORITHM (NICHED PARETO GENETIC ALGORITHM)

The authors of the method are Horn and Nafpliotis who developed an algorithm involving a selection which combines an analysis of individuals domination with a simultaneous tournament selection [1, 3]. This method involves a creation of a comparative set consisting of approximately 10% of the present population. We always take two individuals from the present set of population to create a tournament and each of these individuals is compared to particular individuals from the temporary set.

In such a case when the first individual is dominated by the individuals from the comparative set, and the other one is not, the latter is selected for the reproduction and goes to the temporary population. When both individuals dominate the elements of the comparative subset, the result of the tournament is decided through the method of fitness sharing and both individuals are shifted to the temporary population P’. The same happens when both individuals are dominated by the elements of the comparative subset [6, 12].

According to the authors, such procedures ensure the creation of stable subpopulations along the front of the Pareto-optimal solutions.

The steps of the NPGA algorithm:

1. A set of comparative individuals is picked up randomly from the PG set and the number of them is indicated by the “dominance pressure” value.

2. The individual dominating the random set is shifted to the temporary population P', the individual dominated by the elements of the temporary set is rejected.

3. In the temporary population P', the crossover and mutation operations take place, which leads to a new population – $PG+1$.

4. The procedures described in points 1–5 are repeated until the termination of the algorithm commences (e.g. G = 150).

CONCLUSIONS

The dynamic development of the electric power engineering and the associated increase in the number of connected power loads and sources enforces the use of new, non-traditional methods allowing for a real control of the power grid operation. Thus, the minimization of the balancing costs of electric power systems becomes an essential problem. It is an issue, which combines the OPF problem with reliability of EPS functioning. In practice, controlling the operation of small networks does not involve any serious problems, nevertheless, in case of large systems it is necessary to take advantage of algorithms with solid mathematical foundations. However, in order to solve optimization problems, energy experts more and more often use heuristic methods, which allow to work out satisfactory results.

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